

Solar Neutrino Decay

Andy Acker and Sandip Pakvasa
Department of Physics and Astronomy
University of Hawaii at Manoa

Abstract

We re-examine the neutrino decay solution to the solar neutrino problem in light of the new data from Gallex II and Kamiokande III. We compare the experimental data with the solar models of Bahcall and Pinsonneault and Turck-Chieze and find that neutrino decay is ruled out as a solution to the solar neutrino problem at better than the 98% c.l. even when solar model uncertainties are taken into account.

1 Introduction

It has been pointed out that the inflight decay of solar neutrinos provides a possible solution to the solar neutrino problem[1]. Such scenarios have gained interest as they have been shown capable of providing simultaneous solutions to both the low energy atmospheric neutrino anomaly (via neutrino oscillations) and the solar neutrino problem (via in flight decay) while requiring mixing only between 2 generations[2]. Further, it has recently been shown that certain models implementing these ideas can lead to an observable rate of neutrinoless double beta decay accompanied by majoron emission[3]. In this note we review the phenomenology of solar neutrino decay and re-evaluate this solution to the solar neutrino problem in light of the new results from Gallex[4] as well as Kamiokande[5].

1.1 Neutrino Decay Phenomenology

We begin by reviewing the phenomenology of solar neutrino decay. Let us take ν_e to be a mixture of mass eigenstates ν_i with masses m_i ; $\nu_e = \sum_i U_{ei}\nu_i$ and assume that one of these, say ν_2 , is unstable with a rest frame lifetime of τ_0 . It is implicit that all other neutrino mass eigenstates have lifetimes much greater than the Earth-Sun transit time even for the highest solar neutrino energies. In the presence of neutrino decay the solar ν_e flux is depleted and the spectrum distorted as given by

$$\phi(\nu_e, E) = \phi_\odot(E) \times \{(1 - |U_{e2}|^2)^2 + |U_{e2}|^4 \exp[-t/\tau(E)]\}, \quad (1)$$

where $\tau(E)$ is the lifetime at energy E ($\tau(E) = (E/m_2)\tau_0$), t is the Sun-Earth time of flight, about 480 s, and ϕ_\odot is the SSM ν_e flux. There is, in addition, a ν_μ flux resulting from ν_e conversion which must be accounted for when considering modification to the solar neutrino signal as measured in electron scattering or neutral-current detectors. This is given by

$$\phi(\nu_\mu, E) = \phi_\odot(E)|U_{e2}|^2\{(1 - |U_{e2}|^2)[1 + \exp(-t/\tau(E))]\} \quad (2)$$

in the limit of two-flavor mixing. Hence the spectral suppression is completely determined by two parameters, the lifetime τ and the mixing angle $|U_{e2}|$.

Two models have recently been investigated that give rise to fast neutrino decay in vacuum as required by the solar neutrino problem and are consistent with all laboratory constraints. One class of these models[6] assumes that the neutrinos are Dirac particles, and that the coupling which gives rise to neutrino decay is of the form $g_{21}\nu_{R1}^T C^{-1}\nu_{R2}\chi$ where χ is a light iso-singlet scalar. This coupling leads to the decay in-flight of ν_2 : $\nu_2 \rightarrow \bar{\nu}_{1R} + \chi$. As $\bar{\nu}_{1R}$ is a right-handed singlet the decay products in this model are sterile. A second class of models[7] assumes that neutrinos are Majorana particles and that the coupling responsible for neutrino decay is of the form $g_{21}\nu_{L1}^T C^{-1}\nu_{L2}J$ where J is a Majoron. This coupling leads to the in-flight decay of ν_2 : $\nu_2 \rightarrow \bar{\nu}_1 + J$. In this case $\bar{\nu}_1$ is a superposition of ordinary anti-neutrinos and interacts as a $\bar{\nu}_e$ with probability $|U_{e1}|^2$. Hence in this model the initial solar ν_e flux gives rise to a decay modulated $\bar{\nu}_e$ flux, as an additional signal for the decay[8].

We note that a new class of models[9] has recently been proposed wherein matter effects can induce neutrino decay even if the neutrino is stable in vacuum. This can lead to a very different energy dependence of the solar neutrino flux suppression[10] than that discussed above in the vacuum decay scenario. Detailed numerical calculations of the resultant solar fluxes in such models have not yet been carried out, and we do not comment on the viability of such models as a solution to the solar neutrino problem.

2 Neutrino Decay and Solar Neutrino Data

We now evaluate the viability of the vacuum neutrino decay solution in light of the new data from the ^{71}Ga experiment Gallex and from Kamiokande. The combined results of the ^{71}Ga experiments, SAGE[11], GALLEX I[12] and GALLEX II[4] give 77 ± 13 SNU's, the Homestake ^{37}Cl experiment reports $2.28 \pm .028$ SNU's[13], and the Kamioka water Cerenkov detector reports a flux of $0.51 \pm .07$ [5] of the Bahcall Pinsonneault[14] SSM predictions. These experimental results are given in table 1 as a fraction of predictions of Bahcall Pinsonneault and Turck-Chieze[15] SSM's. The error bars in the data are the 1σ experimental errors divided by the SSM prediction. To take the model uncertainties into account, we also compare the data to the SSMs with the neutrino fluxes at their 1σ upper and lower limits. Thus, for example, the row in table 1 labeled "BP -1σ " gives the experimental results as a fraction of the Bahcall Pinsonneault SSM where all neutrino fluxes are taken to be at the model's 1σ lower limit. In addition, we have included a

comparison of the data to the BP model where the 8B neutrino flux is at its 2σ lower limit.

Table 2 shows the best fit parameters of the neutrino decay solution $|U_{e2}|$ and τ and the corresponding value of χ^2 for each of the Solar Models under consideration. Note that in each case a short lifetime is preferred, we find that, in general, a lab frame lifetime for a 10 MeV neutrino of 30 seconds or less gives approximately the same χ^2 . The best fit occurred for the SSM of Turck-Chieze with all ν_e fluxes at their 1σ lower limit. The minimum χ^2 is 10.7 for three degrees of freedom, hence this solution is excluded at the 98% confidence level. For all other cases tested, in particular the B.P. and T-C SSM's with all neutrino fluxes at their central values, we find that the neutrino decay solution to the solar neutrino problem is ruled out at better than the 99% confidence level.

3 Conclusions

We have re-examined the neutrino decay solution to the solar neutrino problem in light of the new data from Gallex II. We find that the results from the ^{71}Ga , ^{31}Cl , and Kamiokande water Cerenkov detectors can not be simultaneously explained by the in flight decay of solar neutrinos. Assuming either the SSM of Bahcall and Pinsonneault or Turck-Chieze, and taking uncertainties in the predicted solar neutrino flux into account the decay scenario is ruled out at greater than the 98% confidence level.

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Tables

Table 1: Data Compared to SSM's

Solar Model	Cl	Kamioka	Gallium
BP central value	$.28 \pm .03$	$.51 \pm .07$	$.59 \pm .1$
BP $+1\sigma$	$.25 \pm .03$	$.45 \pm .06$	$.56 \pm .1$
BP -1σ	$.33 \pm .03$	$.59 \pm .08$	$.61 \pm .1$
BP -2σ 8B	$.37 \pm .04$	$.72 \pm .10$	$.60 \pm .1$
TC central value	$.36 \pm .04$	$.66 \pm .08$	$.61 \pm .1$
TC $+1\sigma$	$.29 \pm .03$	$.53 \pm .05$	$.56 \pm .1$
TC -1σ	$.46 \pm .05$	$.88 \pm .12$	$.66 \pm .1$

Table 2: Decay Solution Fits

Solar Model	Lifetime	$ U_{e2} $	χ^2
BP central value	0	.635	13.7
BP $+1\sigma$	0	.672	13.2
BP -1σ	0	.622	12.8
BP -2σ 8B	0	.583	11.7
TC central value	0	.582	12.3
TC $+1\sigma$	0	.634	16.6
TC -1σ	0	.514	10.7

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